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(19)

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(54) HEAT EXCHANGER

(71) We, U.S. PHILIPS CORPORATION, of 345 Scarborough Road, Briarcliff Manor, New York, United States of America; a Corporation organized and established under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a regenerator which comprises a housing filled with a mass of spherical heat-storage elements.

Such a regenerator is known and is used, for example, in cold-gas refrigerators and other devices for producing cold. In these regenerators, the flow of a compressed medium in one direction through the regenerator alternates with the flow of an expanded medium in the opposite direction. The compressed medium gives up thermal energy to the filling mass, and this thermal energy is absorbed again from the filling mass by the expanded medium.

The use of spherical heat-storage elements presents the advantage of a comparatively simple and cheap construction of the regenerator, while due to the fact that the spherical elements have only a point contact with each other, the thermal conductivity in the direction of flow of the regenerator is low.

The regenerator filling mass of the cold-producing device described in the United States patent specification 3,218,815 consist of solid metal spheres of, for example, lead or bronze. At very low temperatures such spheres do not have a sufficiently large specific heat and consequently an insufficient amount of thermal energy can be stored in the filling mass and be absorbed therefrom in each cycle of the cold-producing device, thence, using this known regenerator, it is not possible to achieve extremely low temperatures.

It is an object of the present invention to provide a regenerator which operates satisfactorily at extremely low temperatures.

According to the invention there is provided a regenerator comprising a housing filled with a mass of the heat storage elements consisting of hollow carbon spheres having gas-permeable walls and filled with helium.

The specific heat of helium increases when the temperature decreases, in contrast with the specific heat of materials conventionally used for regenerators, such as lead, copper and gold, which decreases when the temperature decreases. Since at 60°K the specific heat of copper is negligibly small and that of lead is approximately 0.009 J/ccm°K, for helium under a pressure of 4 atm. the specific heat is approximately 0.165 J/ccm°K.

It has been found possible to introduce helium into the cavities within the hollow carbon spheres in a simple manner by diffusion through the walls of the spheres. In this manner an inexpensive regenerator is obtained which below 10°K has a heat capacity larger than that of the known regenerator having spherical heat-storage elements as a filling mass.

Since the hollow carbon spheres again have only a point contact with each other, the thermal conductivity in the direction of flow of the medium through the regenerator is low.

In one embodiment of the regenerator according to the invention, the hollow carbon spheres have an outer diameter of at least 5μ and at most 150μ.

The wall thickness of the hollow carbon spheres is preferably at least 1μ and at most 2μ. With such a wall thickness the mechanical rigidity of the hollow carbon spheres is sufficiently large for the spheres to be used as a regenerator filling mess.

When a regenerator having a filling mass of helium-filled hollow carbon spheres with gas-permeable walls is incorporated in a refrigerator in which a working medium, for example helium, undergoes a closed thermodynamic cycle, in which the medium flows to and fro through the filling mass, heat trans-

fer takes place between the working medium and the helium inside the spheres *via* the walls of the carbon spheres and thermal energy is alternately given up to and absorbed from the helium inside the spheres.

In addition to the storage of helium in the cavities, also some helium will always be absorbed in the wall surface of the spheres, which increases the heat capacity of the regenerator.

The invention furthermore relates to a method of manufacturing the above-described regenerator. In this method several hollow carbon spheres having gas-permeable walls are simultaneously evacuated and then exposed to a helium atmosphere so that helium gas diffuses through the walls of the spheres to the cavities inside the spheres, the spheres then being arranged in a housing.

The hollow carbon spheres are preferably heated during the evacuation. This accelerates the evacuation.

The helium is preferably kept under a pressure greater than atmosphere pressure during the diffusion. The greater the helium pressure the greater is the rate of diffusion.

In order that the invention may be readily carried into effect, an example will now be described with reference to the accompanying drawings, in which

Fig. 1 is a graph showing the variation of the volumetric specific heat of lead, gold, copper and helium, respectively, (at 4 atm. pressure) in the range from 0—40°K, and

Fig. 2 is a sectional view of a portion of a regenerator of which the filling mass consists of hollow helium-filled carbon spheres having gas-permeable walls.

As shown in figure 1, in which ρc is shown as a function of T (ρ=density, c=specific heat, T=temperature), the specific heat of lead, gold and copper decreases sharply as the temperature decreases. In the region of 6°K. which is of practical importance, the specific heat of gold and copper are nearly zero, while the specific heat of lead is approximately 0.08 J/ccm°K.

In marked contrast with this is the specific heat curve of helium which as shown by the curve in Fig. 1, rises when the temperature decreases. At 6°K the specific heat of helium at a pressure of 4atm. is approximately 0.165 J/ccm°K or almost double that of lead.

This favourable property of helium, namely a high specific heat at very low temperatures, is advantageously used in the regenerator according to the invention, in which helium is stored in hollow carbon spheres having gas-permeable walls, which spheres form the regenerator filling mass. At very low temperatures, such a regenerator has a sufficiently large heat capacity.

The helium is introduced into the spheres by diffusion through the gas-permeable walls of the spheres after having first evacuated the spheres.

Fig. 2 shows a part of a regenerator housing 1 in which the carbon spheres 2 are accomodated. The regenerator housing 1 is closed at its ends by cover plates 3 of which only a portion of one is shown. The cover plates are provided with apertures (not shown) for the inlet and outlet respectively, of the medium which flows through the regenerator.

WHAT WE CLAIM IS:—

1. A regenerator comprising a housing filled with a mass of spherical heat-storage elements consisting of hollow carbon spheres having gas-permeable walls, and filled with helium.

2. A regenerator as claimed in Claim 1, wherein the hollow carbon spheres have an outer diameter of at least 5μ and at most 150μ.

3. A regenerator as claimed in Claim 2, wherein the wall thickness of the hollow carbon spheres is at least 1μ annd at most 2μ.

4. A method of manufacturing the regenerator as claimed in Claim 1, 2 or 3, wherein several hollow carbon spheres having gas-permeable walls are simultaneously evacuated and then exposed to a helium atmosphere so that helium gas diffuses through the walls of the spheres into the cavities inside the spheres the spheres then being arranged in a housing.

5. A method as claimed in Claim 4, wherein the hollow carbon spheres are heated during the evacuation.

6. A method as claimed in Claim 4 or 5, wherein during the diffusion the helium gas is kept under a pressure, greater than atmospheric pressure.

7. A regenerator, substantially as herein described with reference to the accompanying drawings.

8. A method of manufacturing a regenerator substantially as herein described with reference to the accompanying drawings.

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1367618 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

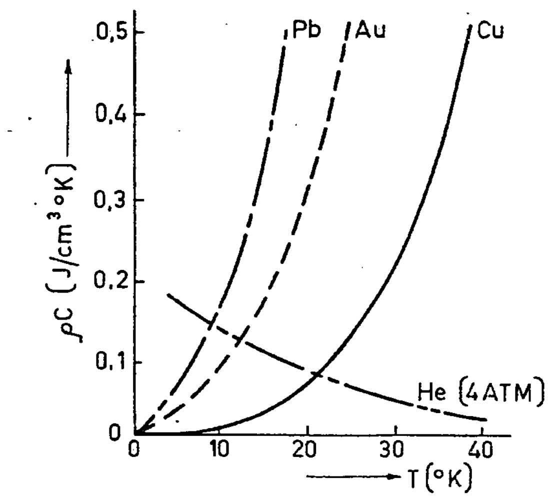

Fig. 1

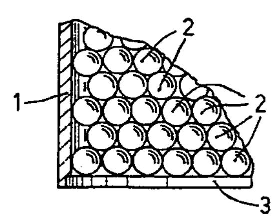

Fig. 2